Delineating Intrinsic Connectivity Networks for Emotional Salience Processing and Executive Control

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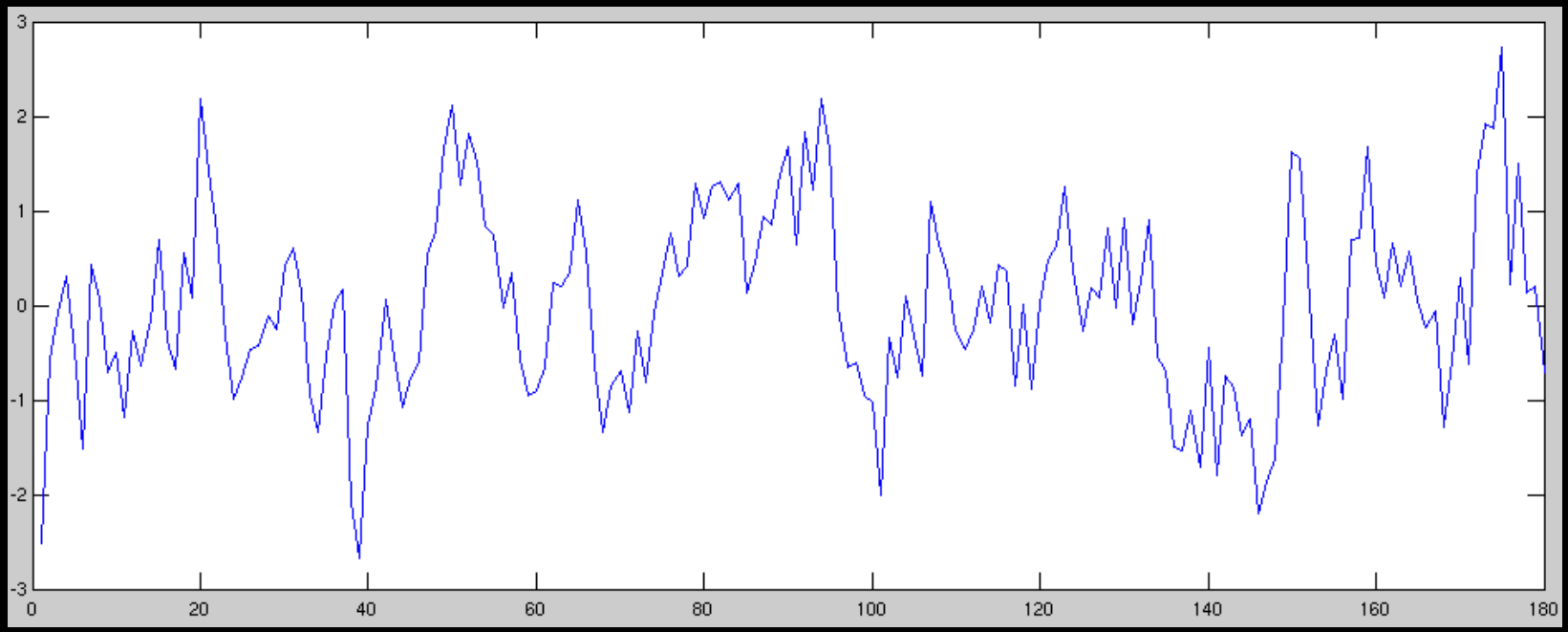
Overview

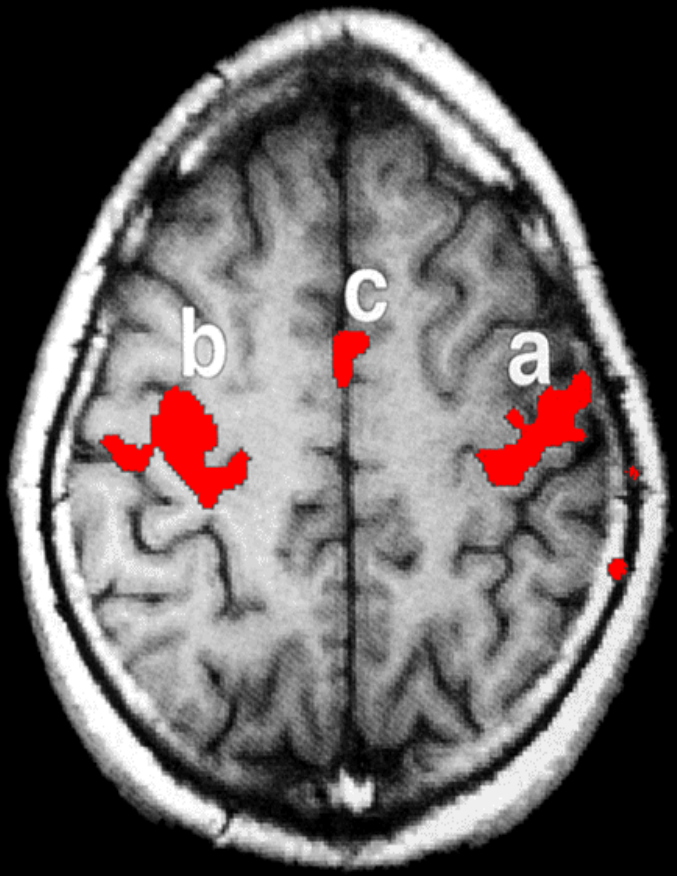
- Resting-state fMRI: Intrinsic connectivity networks
- Emotional salience and executive control networks
- Assigning putative functions to ICNs
- Inter-network interactions
- Implications for addiction research

Resting-State Functional Connectivity

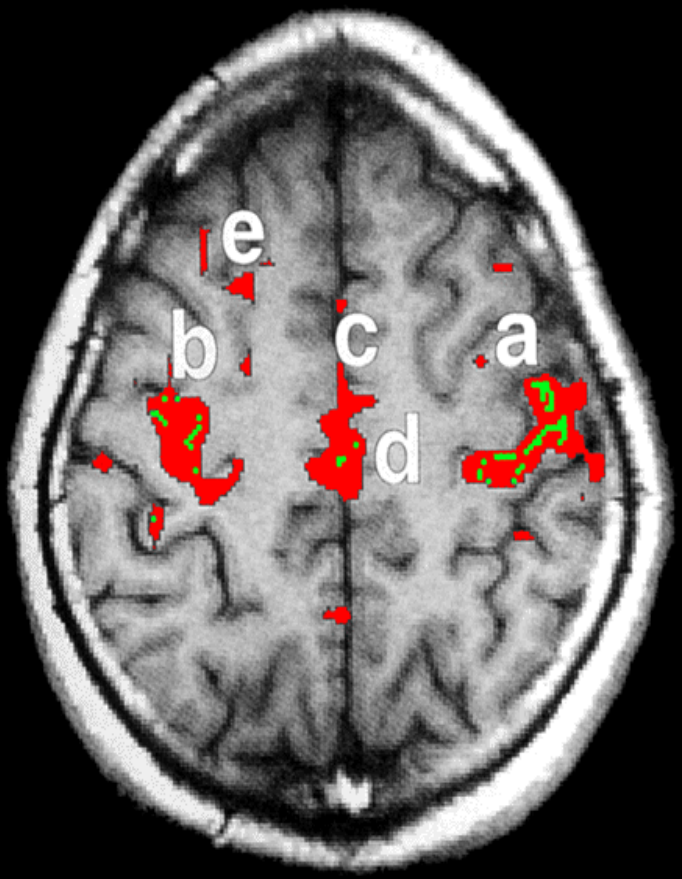
- Brain activity continues in the absence of an externally-cued task
- Brain regions have spontaneous fluctuations in BOLD signal
- A brain region's "resting" BOLD signal timecourse can be used as the regressor



Resting Motor Cortex Connectivity



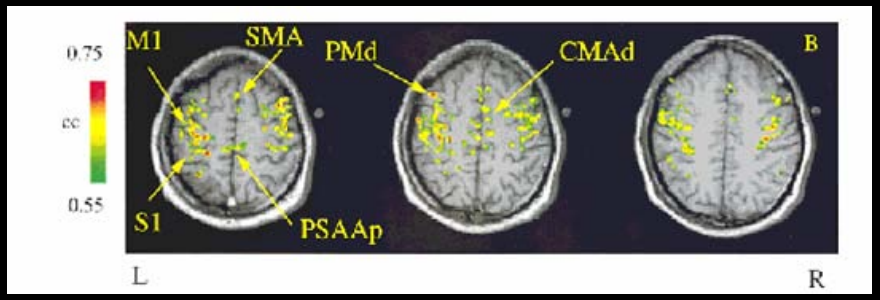
Motor Cortex Defined by *f*MRI



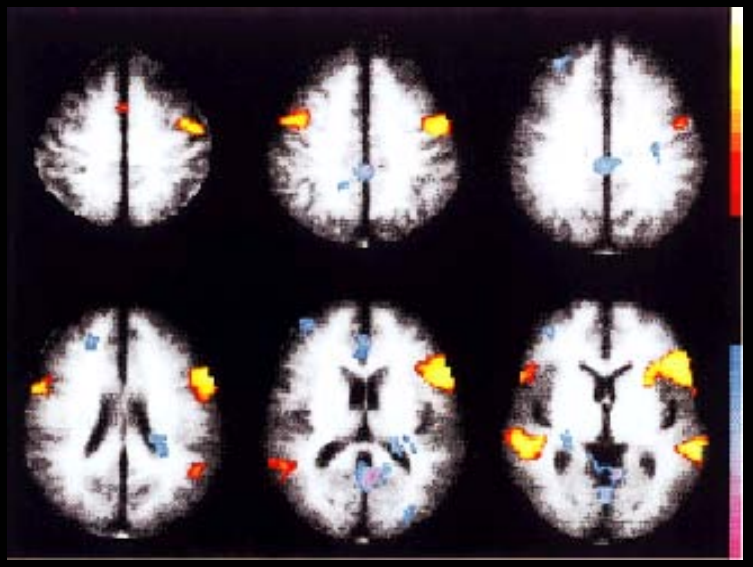
Spontaneous Correlations with Motor Cortex

Biswal, et al., *Magn Reson Med*, 1995

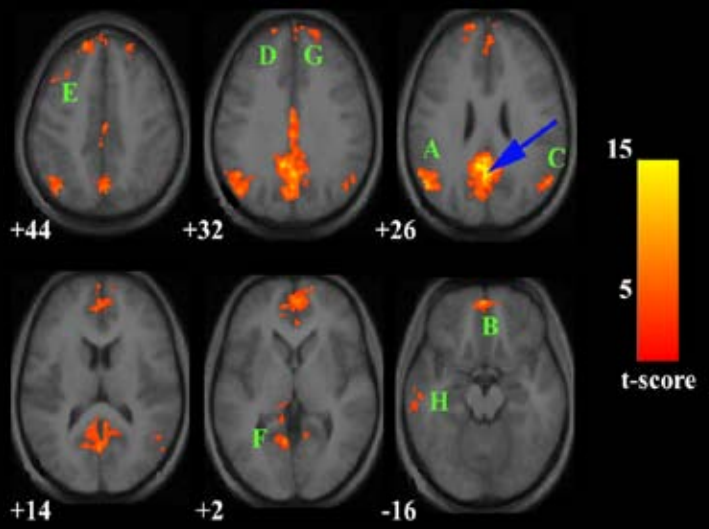
ROI-Derived Intrinsic Connectivity Networks



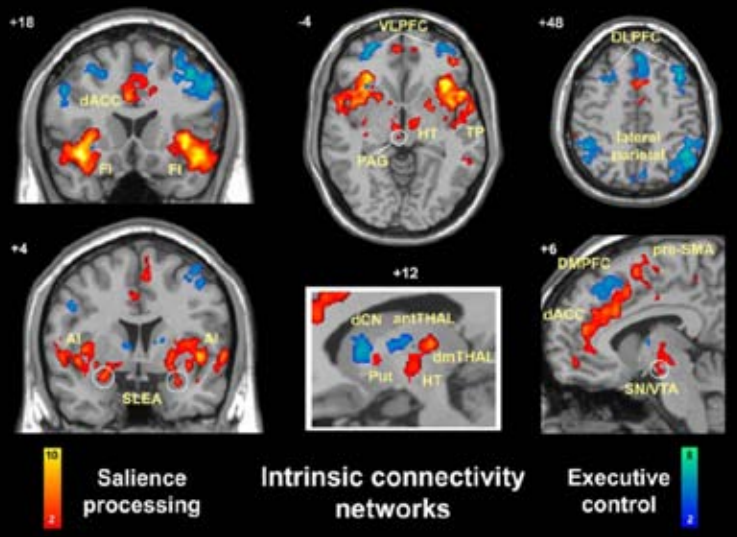
Motor: Xiong et al., 1999



Language: Hampson et al., 2002



Default Mode: Greicius et al., 2003

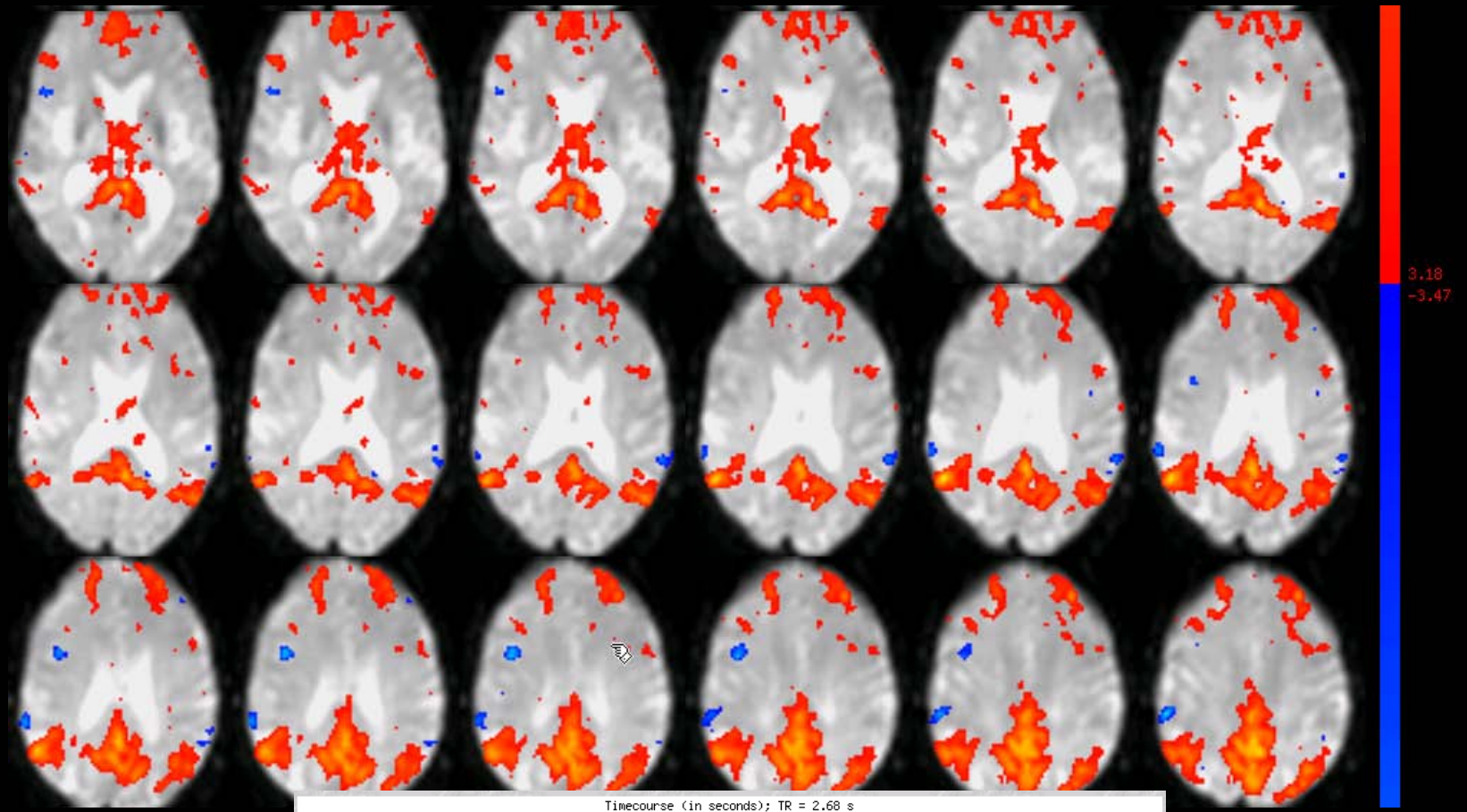


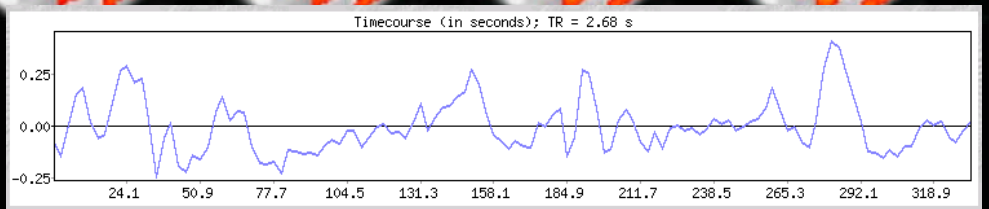
Executive control and Salience: Seeley et al., 2007

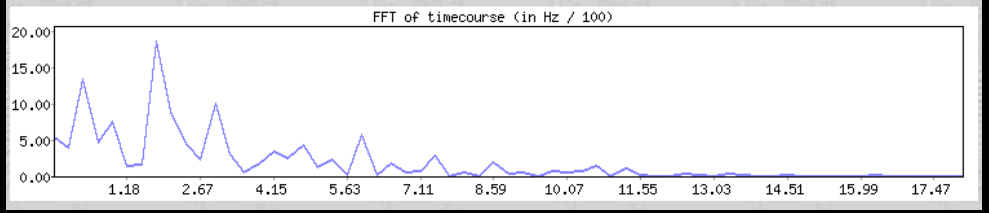
Independent Component Analysis in the Detection of Intrinsic Connectivity Networks

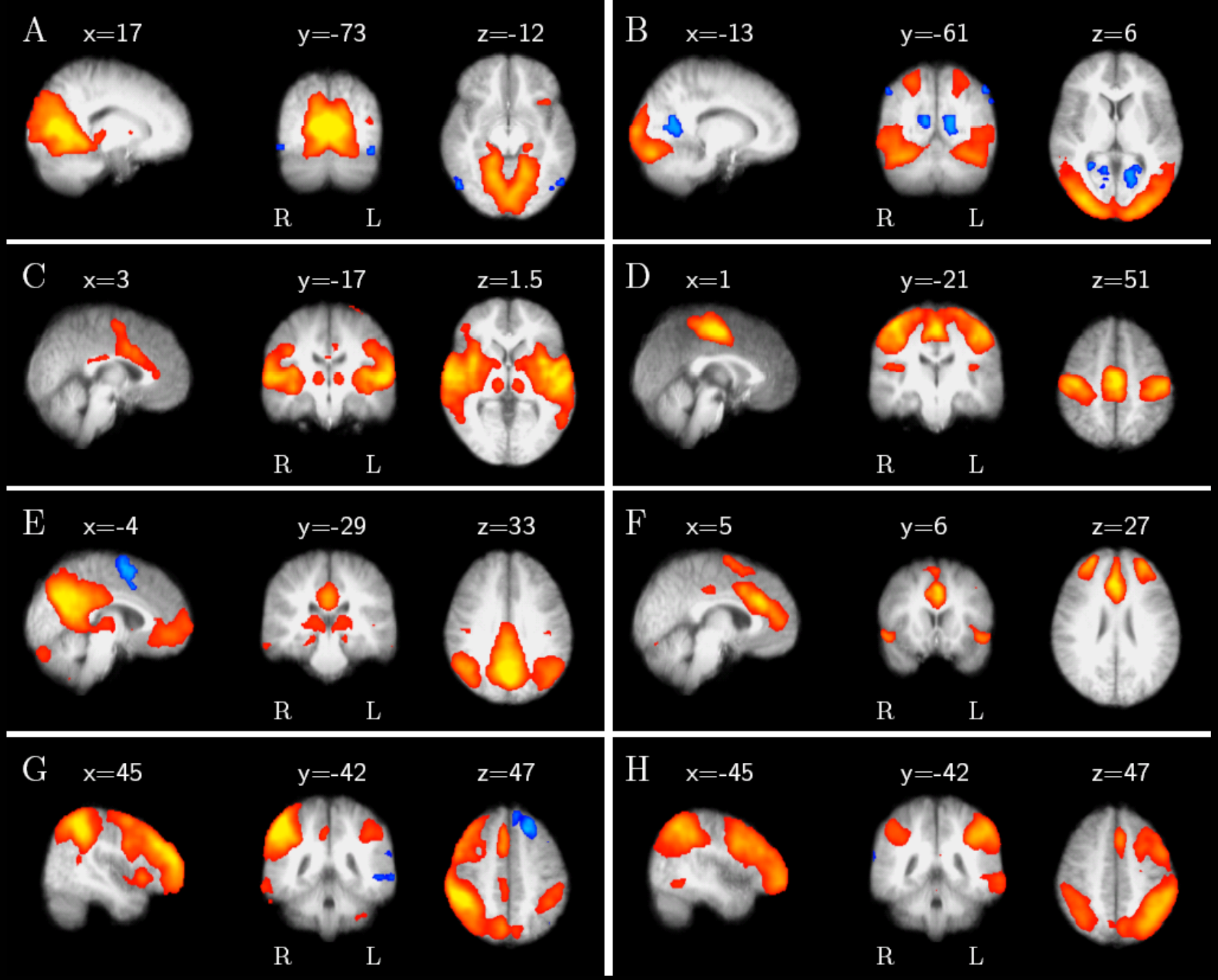
- Separates fMRI signal into independent spatial maps with associated timeseries
- Allows for removal of noisy components
- Reliably extracts several networks, en bloc, as independent components

Default-Mode Network Detected with ICA



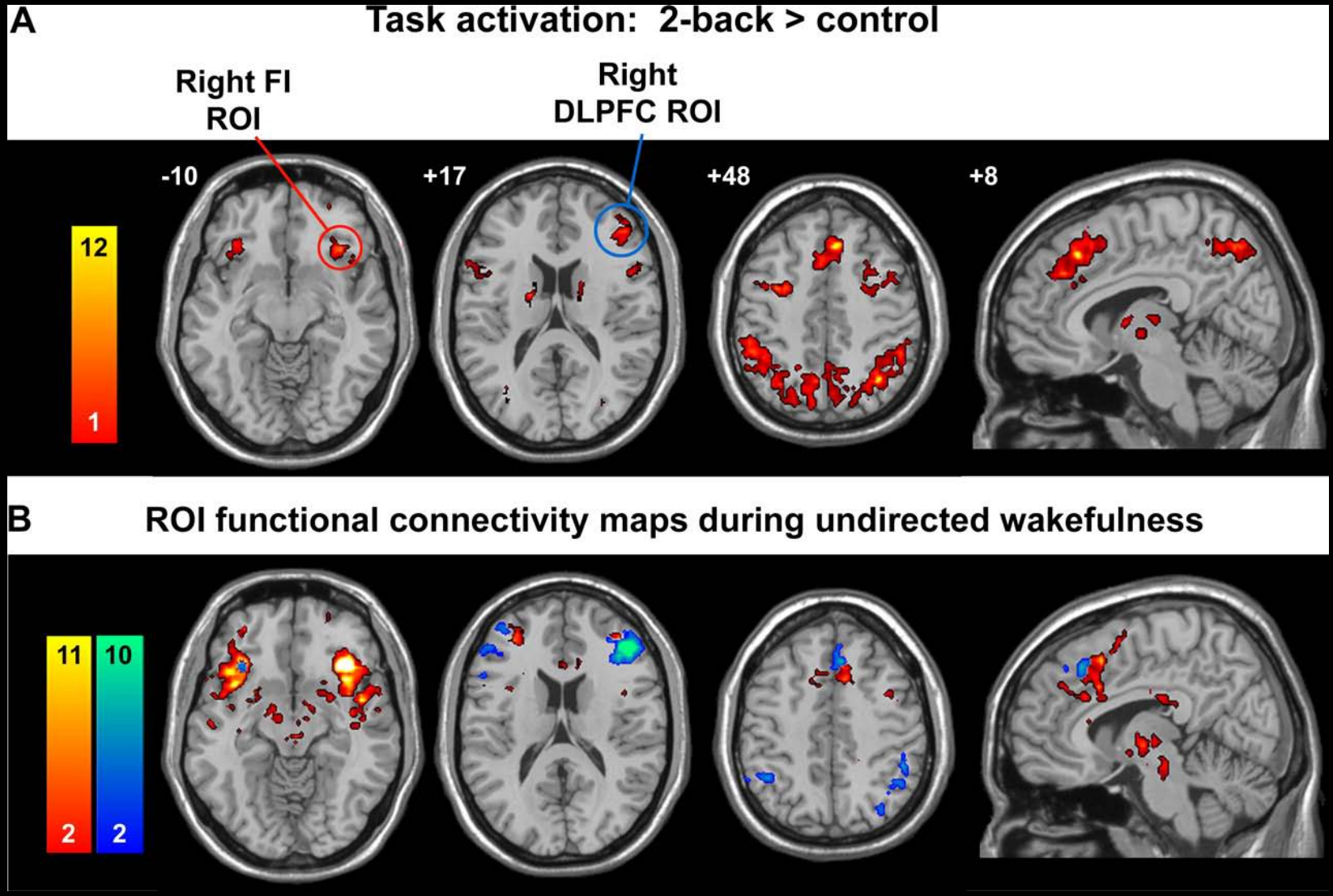






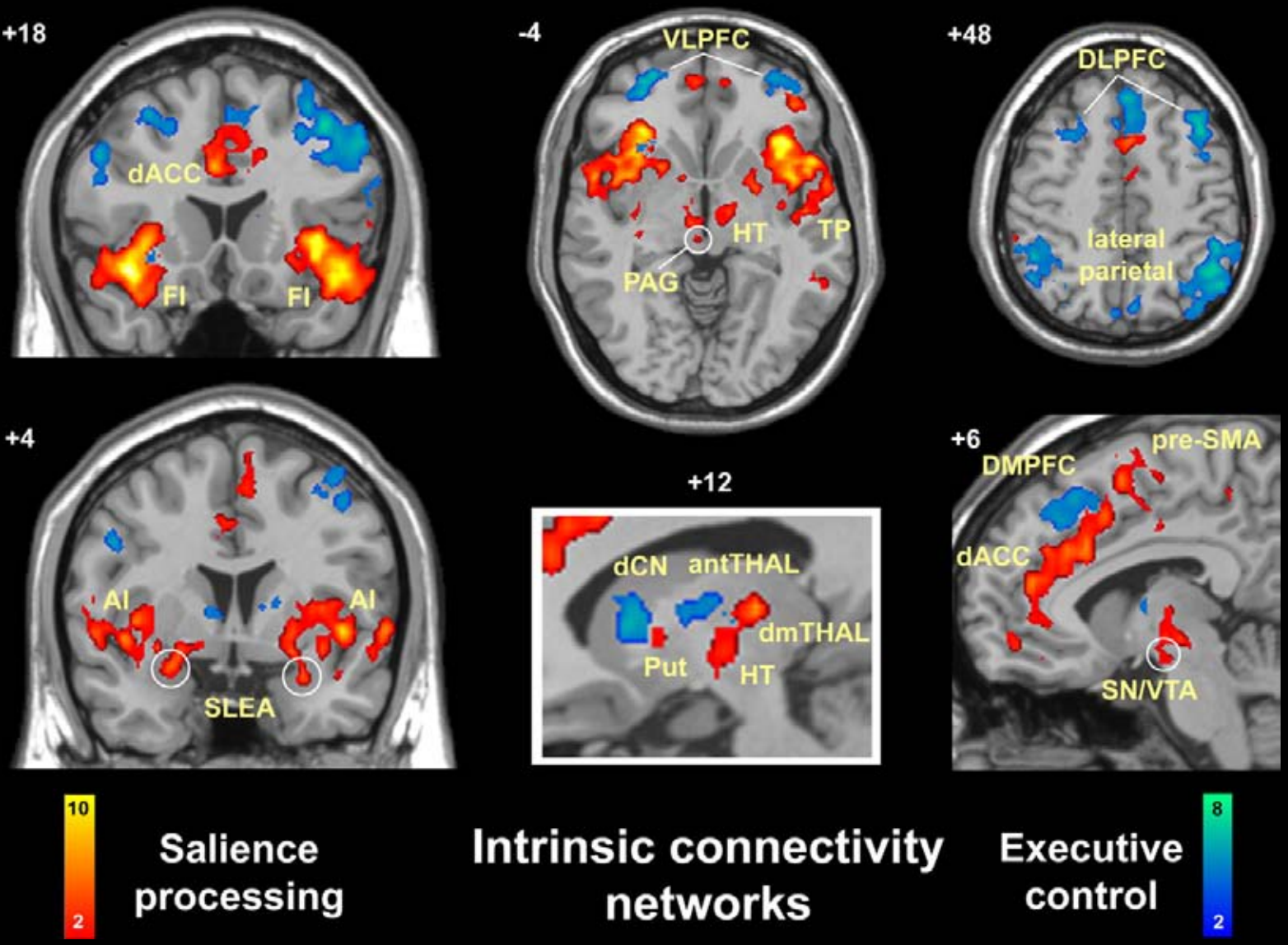
Beckmann et al., *Philos Trans R Soc Lond*, 2005

One Task Activation Network, Two ICNs



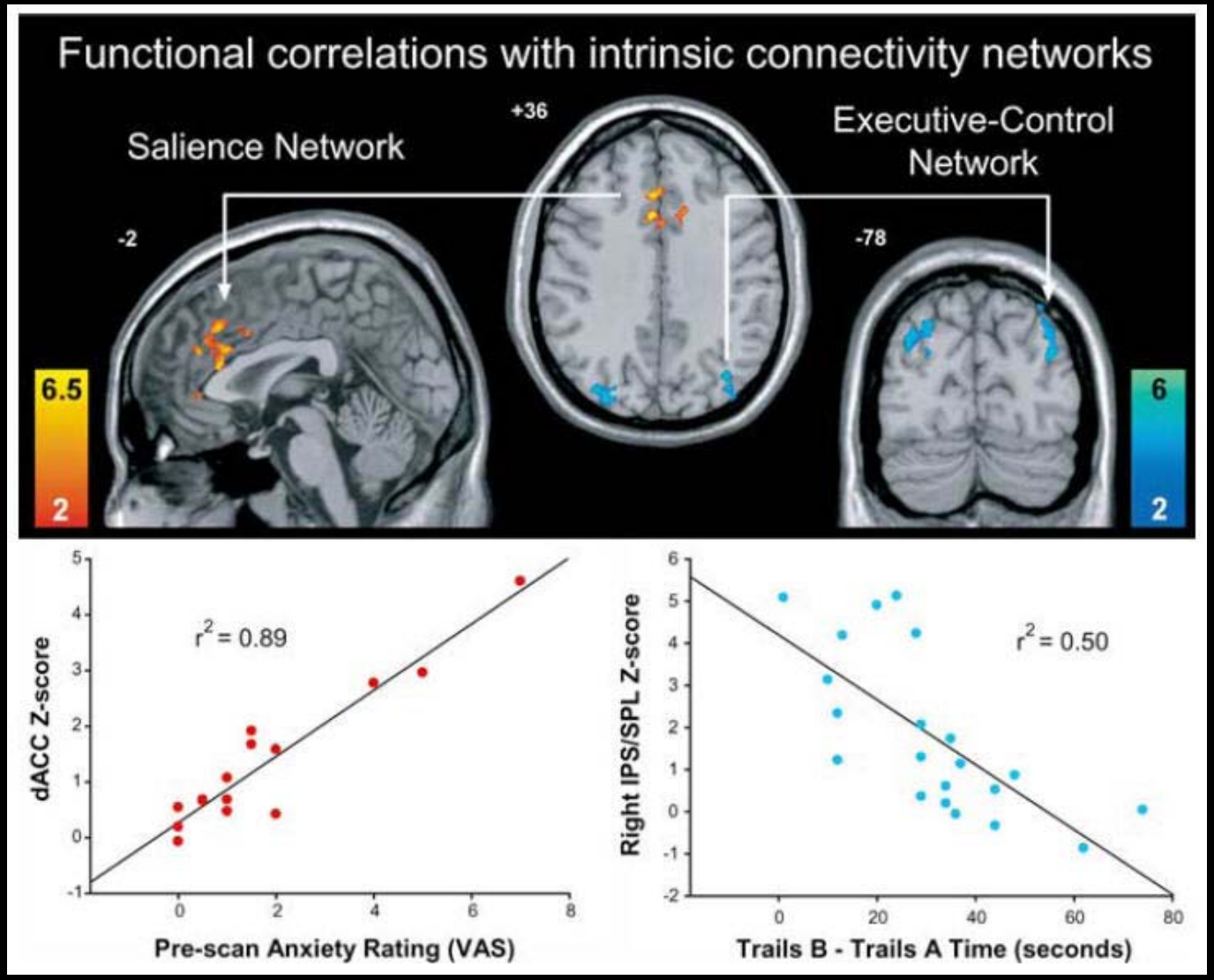
Seeley et al., *J Neurosci*, 2007

Replication in a Separate Sample Using ICA



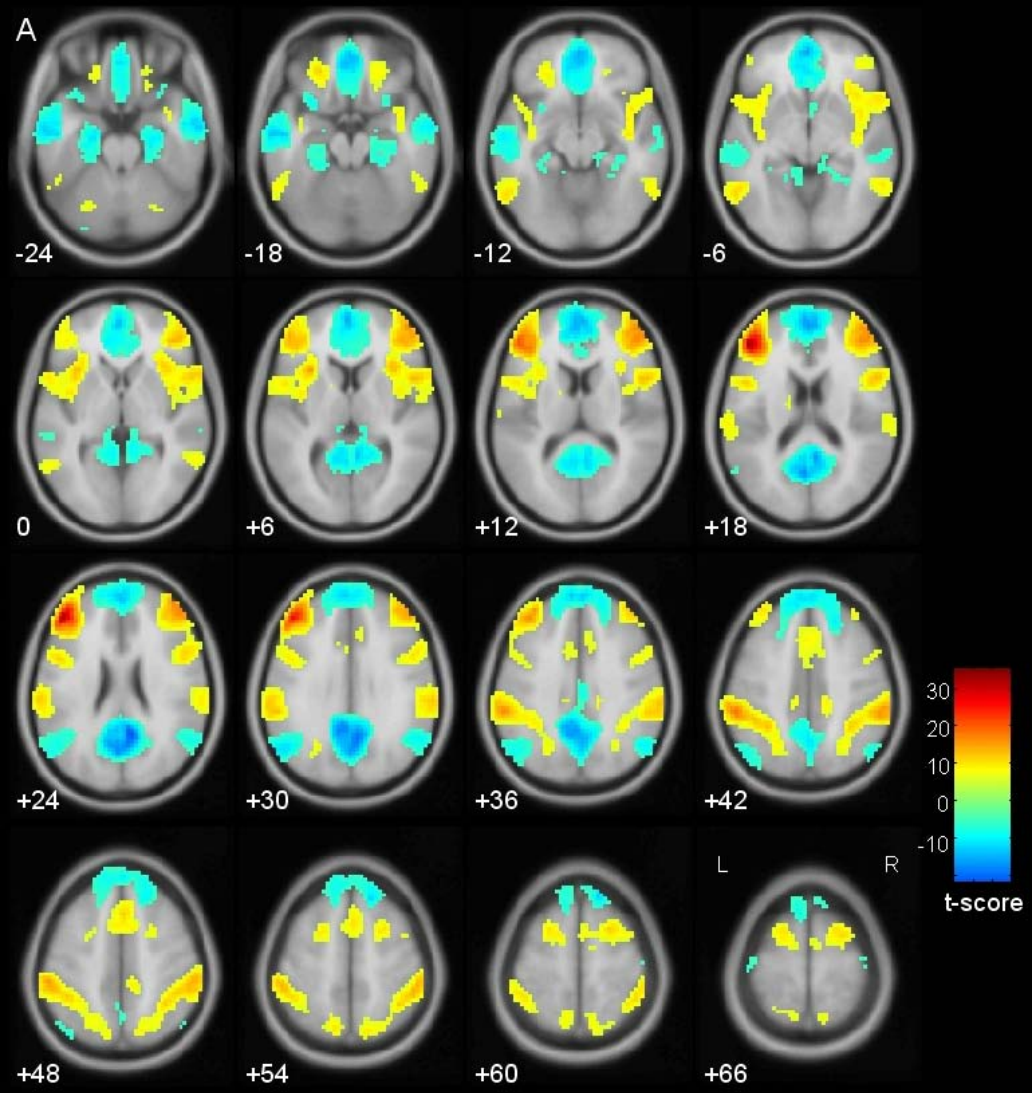
Seeley et al., *J Neurosci*, 2007

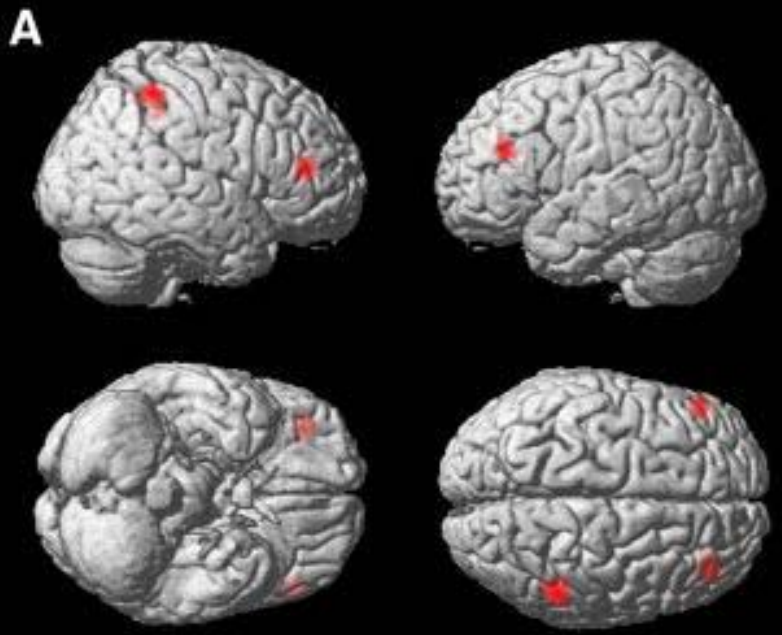
Behavioral Double Dissociation



Seeley et al., *J Neurosci*, 2007

ECN Correlates with IQ





Song et al., *Neuroimage*, 2008

The Cognitive Control Network

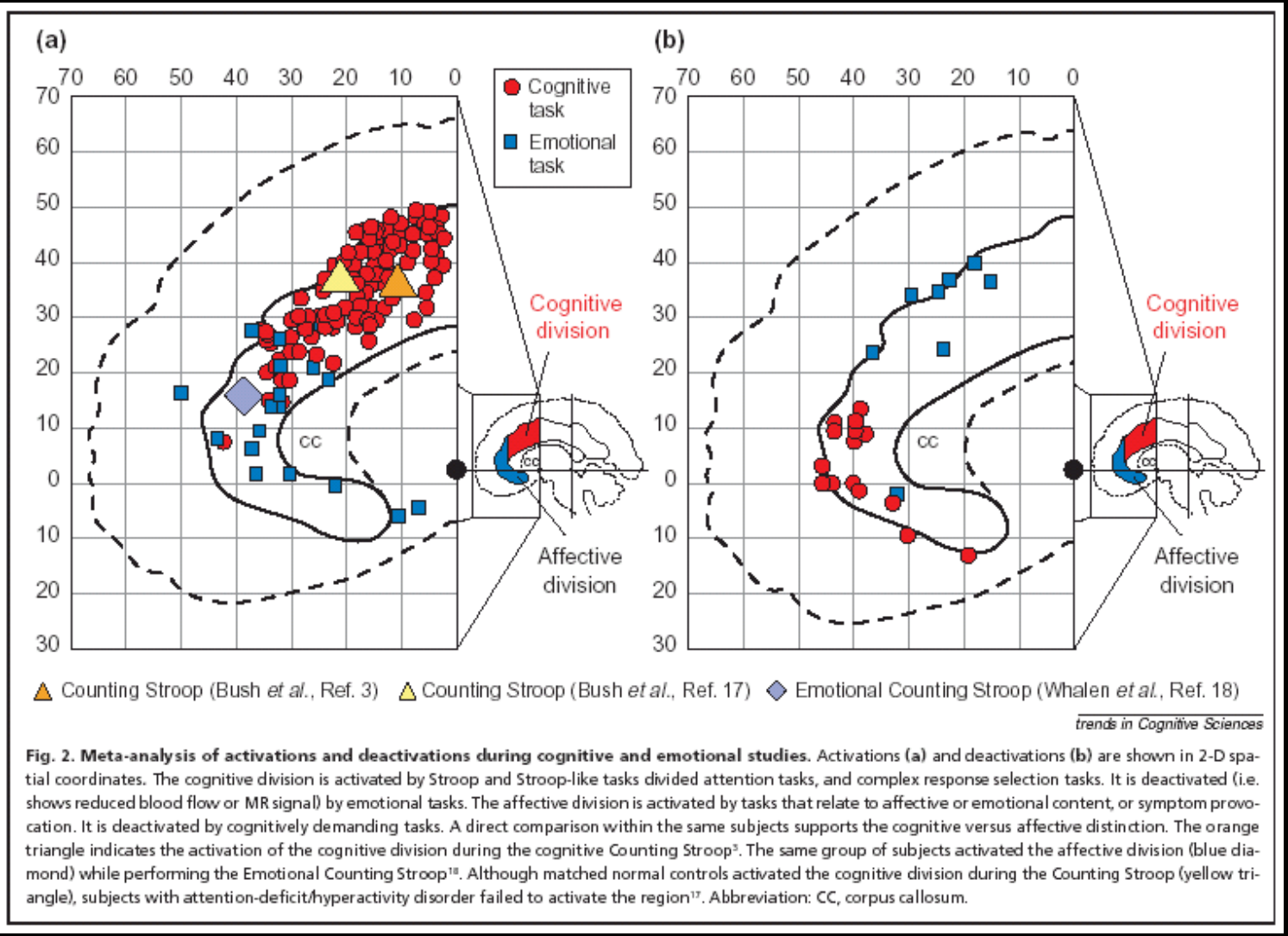
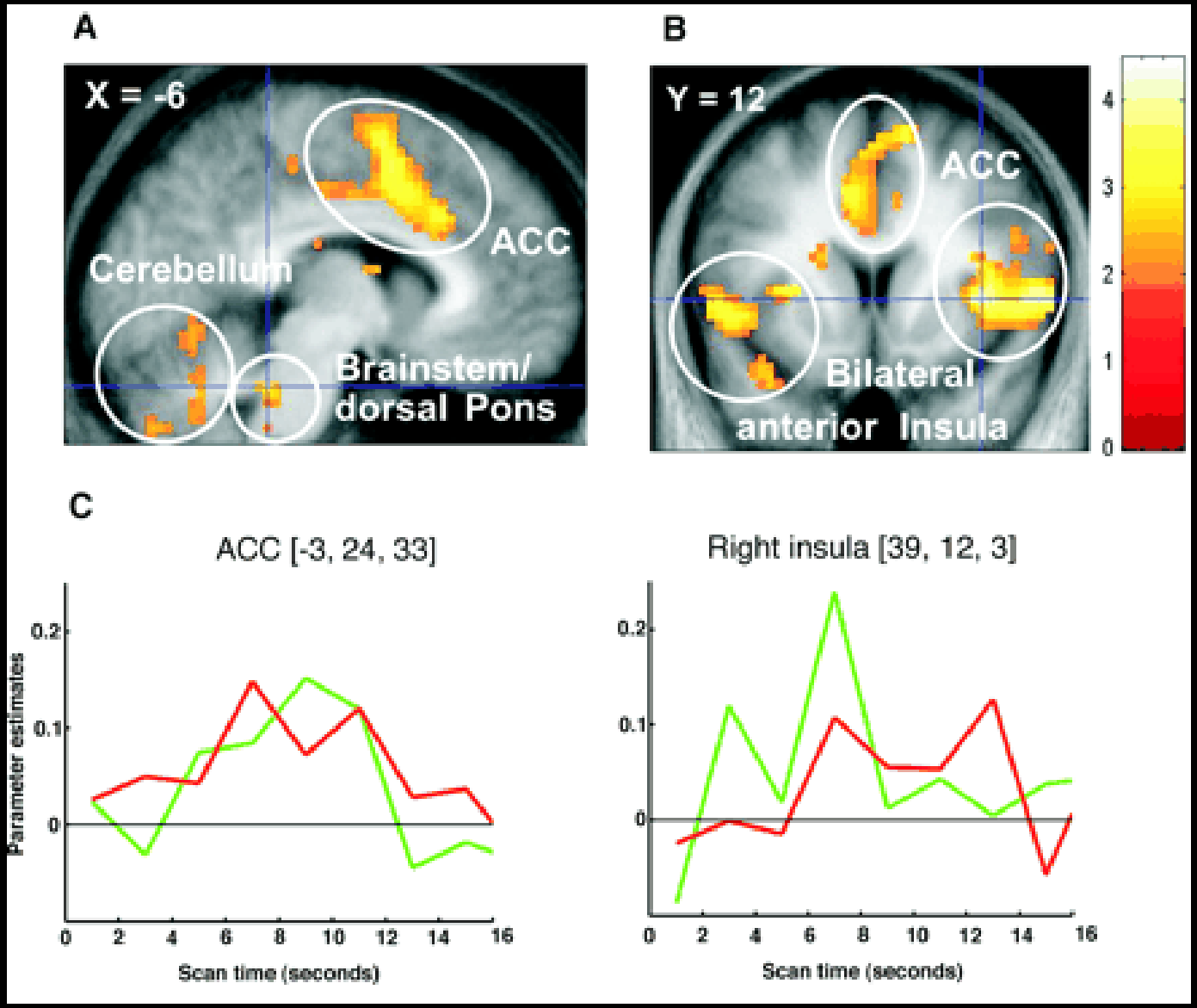


Fig. 2. Meta-analysis of activations and deactivations during cognitive and emotional studies. Activations **(a)** and deactivations **(b)** are shown in 2-D spatial coordinates. The cognitive division is activated by Stroop and Stroop-like tasks divided attention tasks, and complex response selection tasks. It is deactivated (i.e. shows reduced blood flow or MR signal) by emotional tasks. The affective division is activated by tasks that relate to affective or emotional content, or symptom provocation. It is deactivated by cognitively demanding tasks. A direct comparison within the same subjects supports the cognitive versus affective distinction. The orange triangle indicates the activation of the cognitive division during the cognitive Counting Stroop[3]. The same group of subjects activated the affective division (blue diamond) while performing the Emotional Counting Stroop[18]. Although matched normal controls activated the cognitive division during the Counting Stroop (yellow triangle), subjects with attention-deficit/hyperactivity disorder failed to activate the region[17]. Abbreviation: CC, corpus callosum.

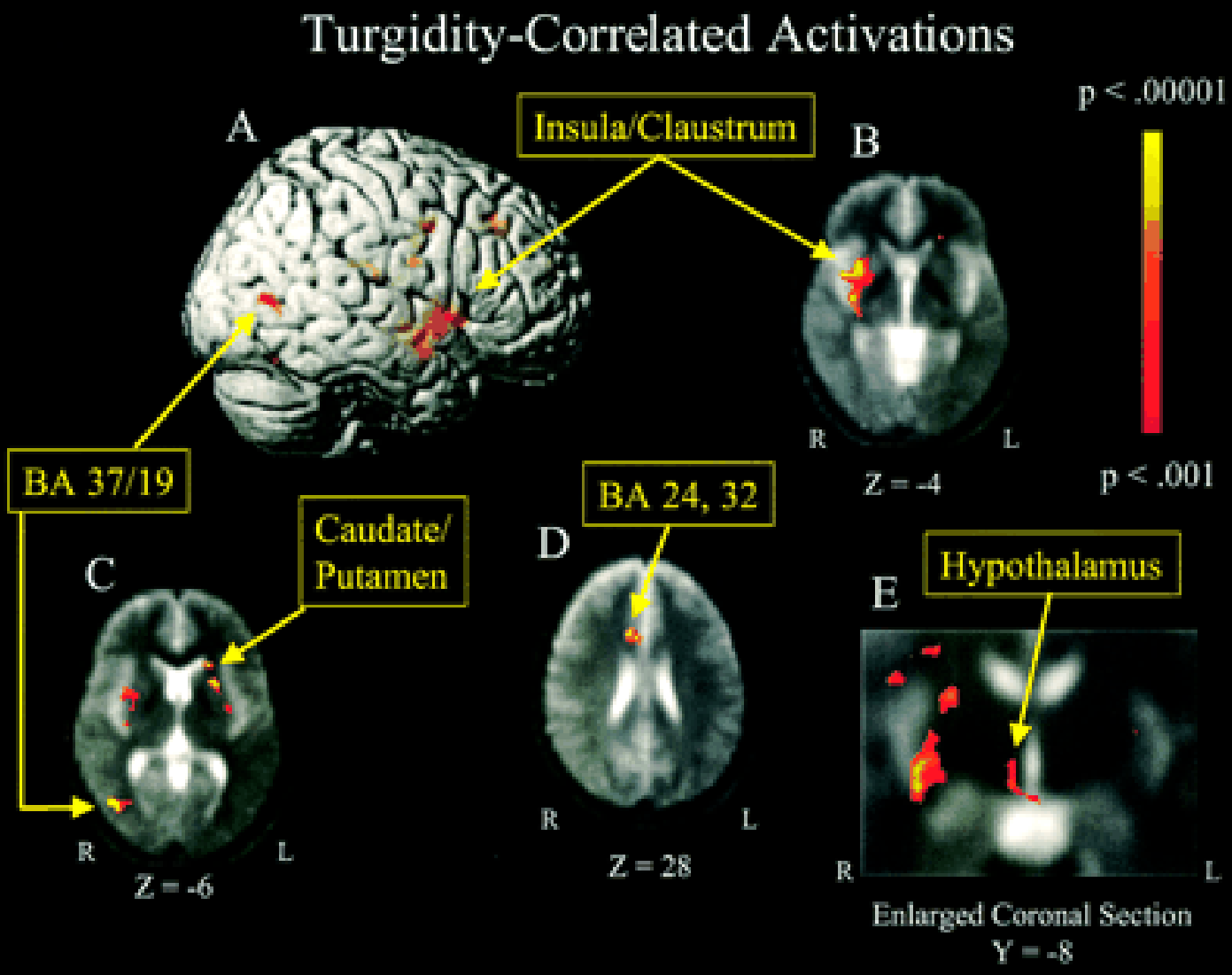
Bush et al., *Trends Cogn Sci*, 2000

The Pain Network



Singer et al., *Science* 2004

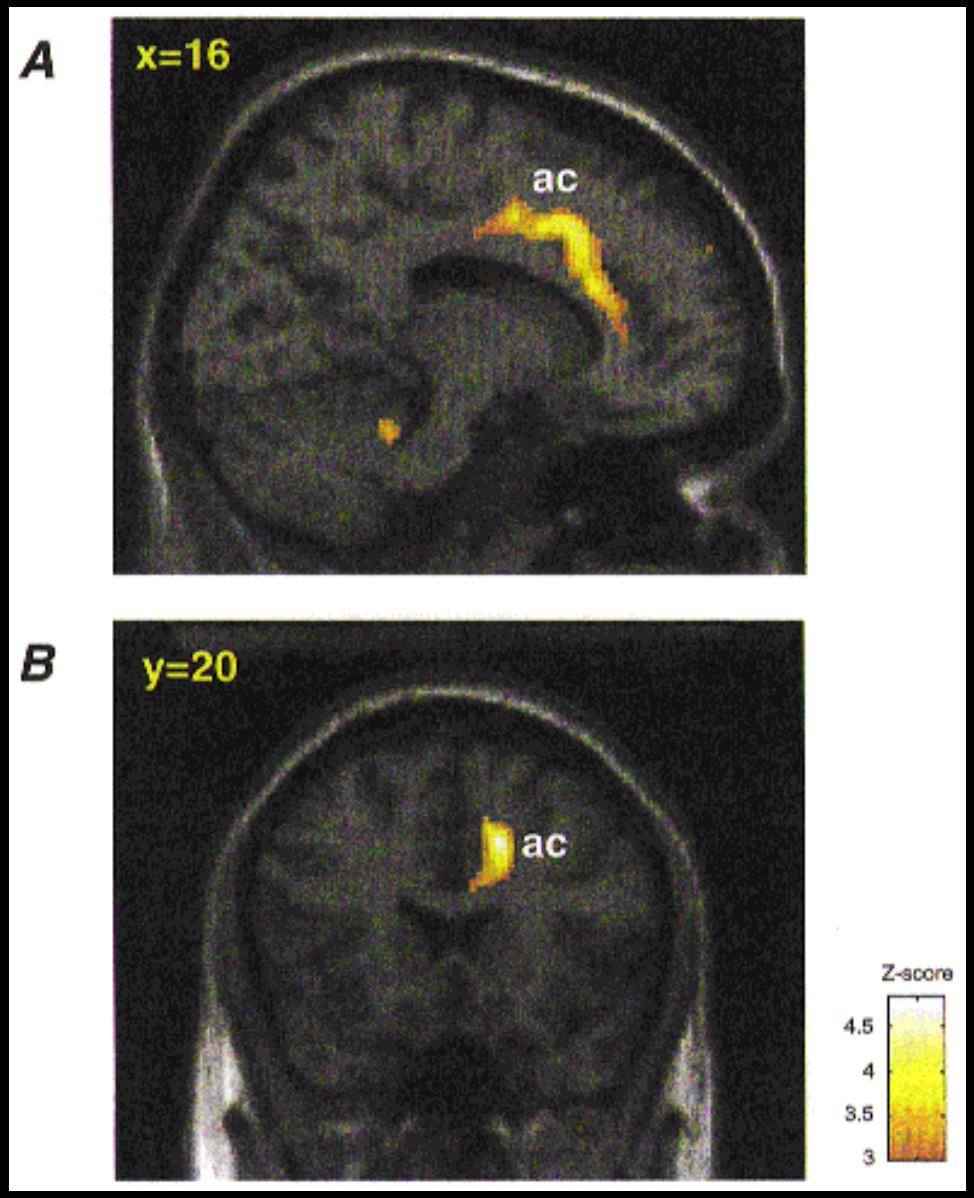
The Turgidity Network



Arnow et al., *Brain* 2002

The Autonomic Nervous System Network

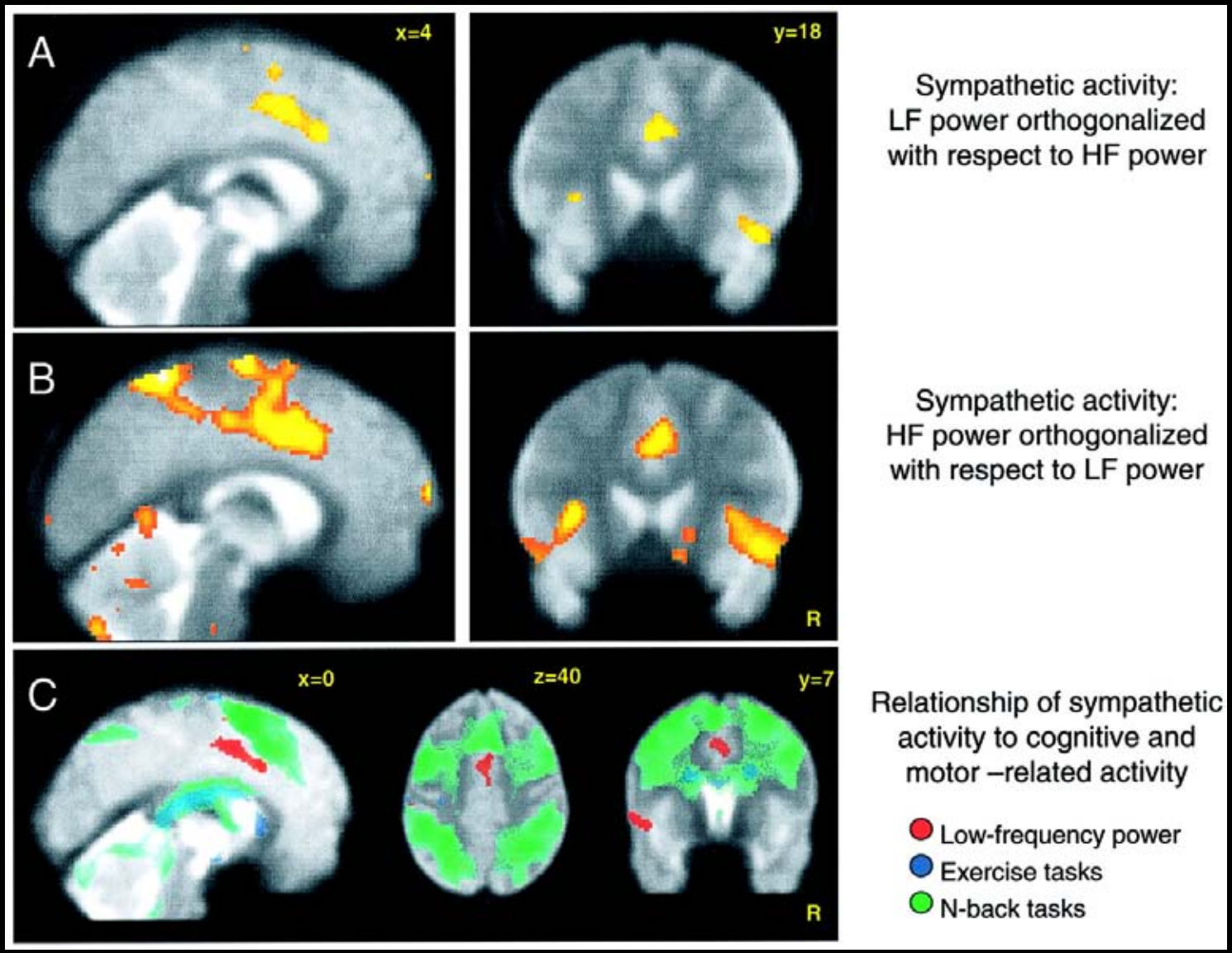
Blood pressure during arthimetic and exercise tasks (PET)



Critchley et at., *J Physiol* 2000

The Autonomic Nervous System Network

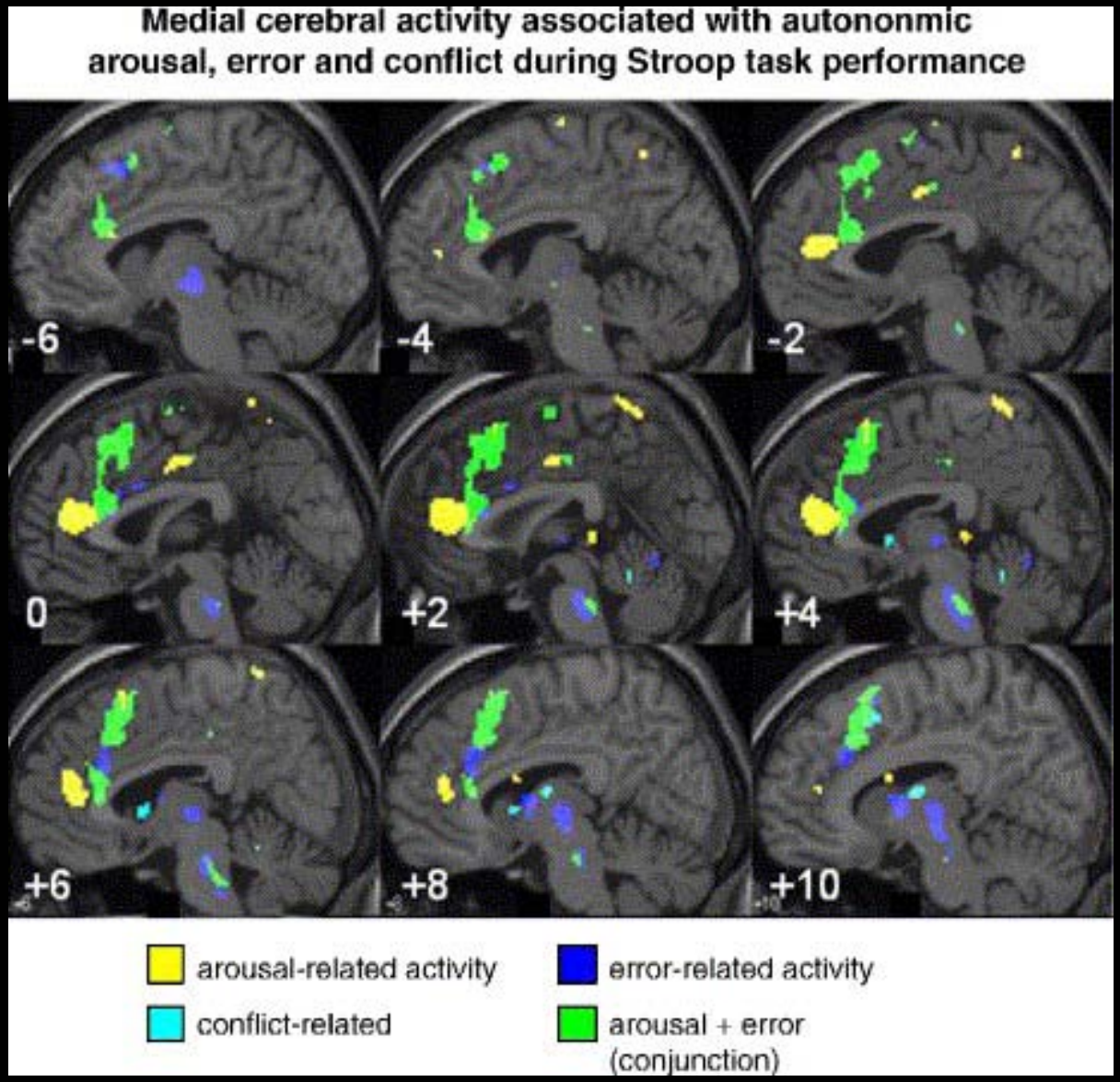
Heart rate during N-back and exercise



Critchley et al., *Brain* 2003

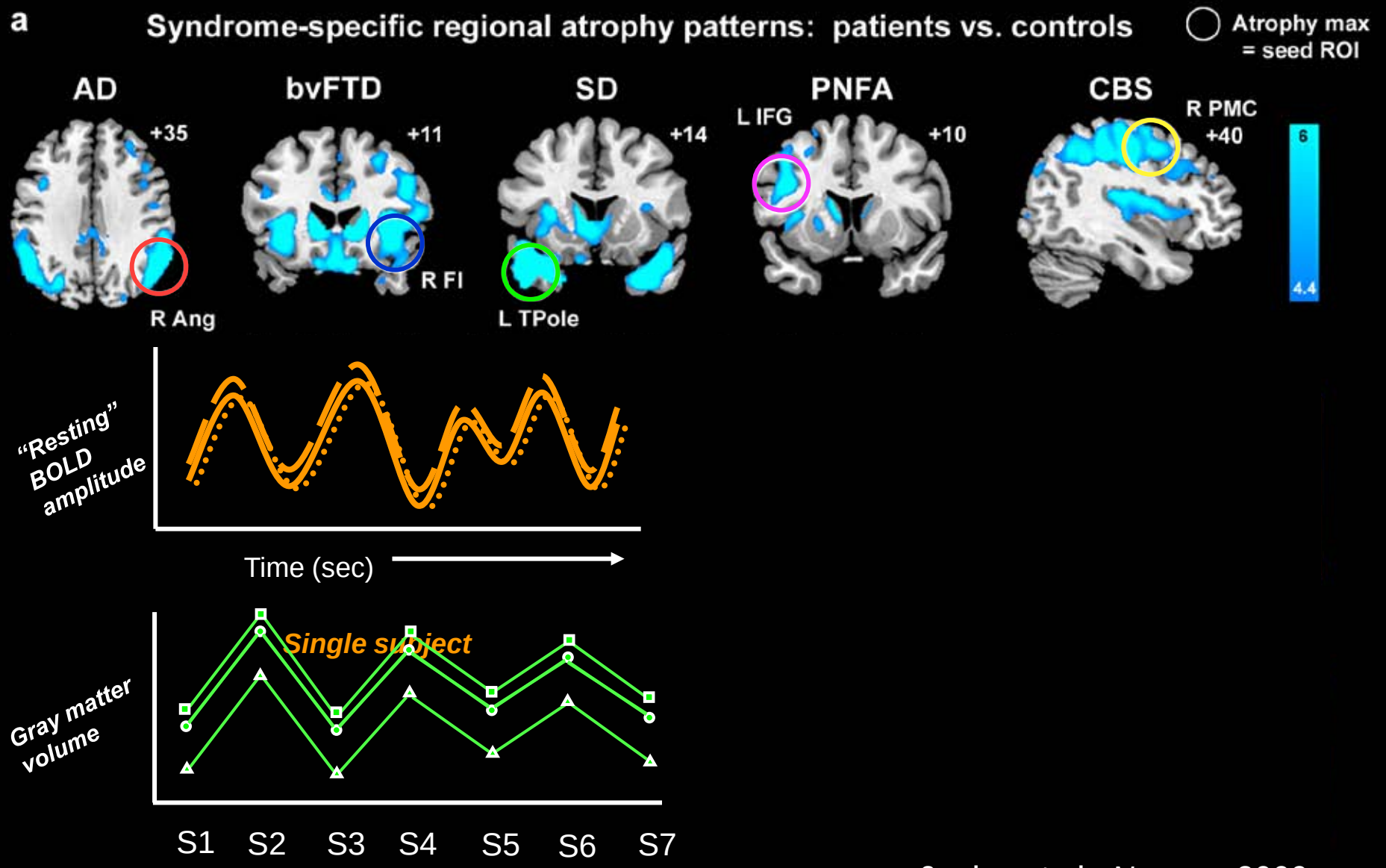
The Autonomic Nervous System Network

Pupillary response during Stroop task



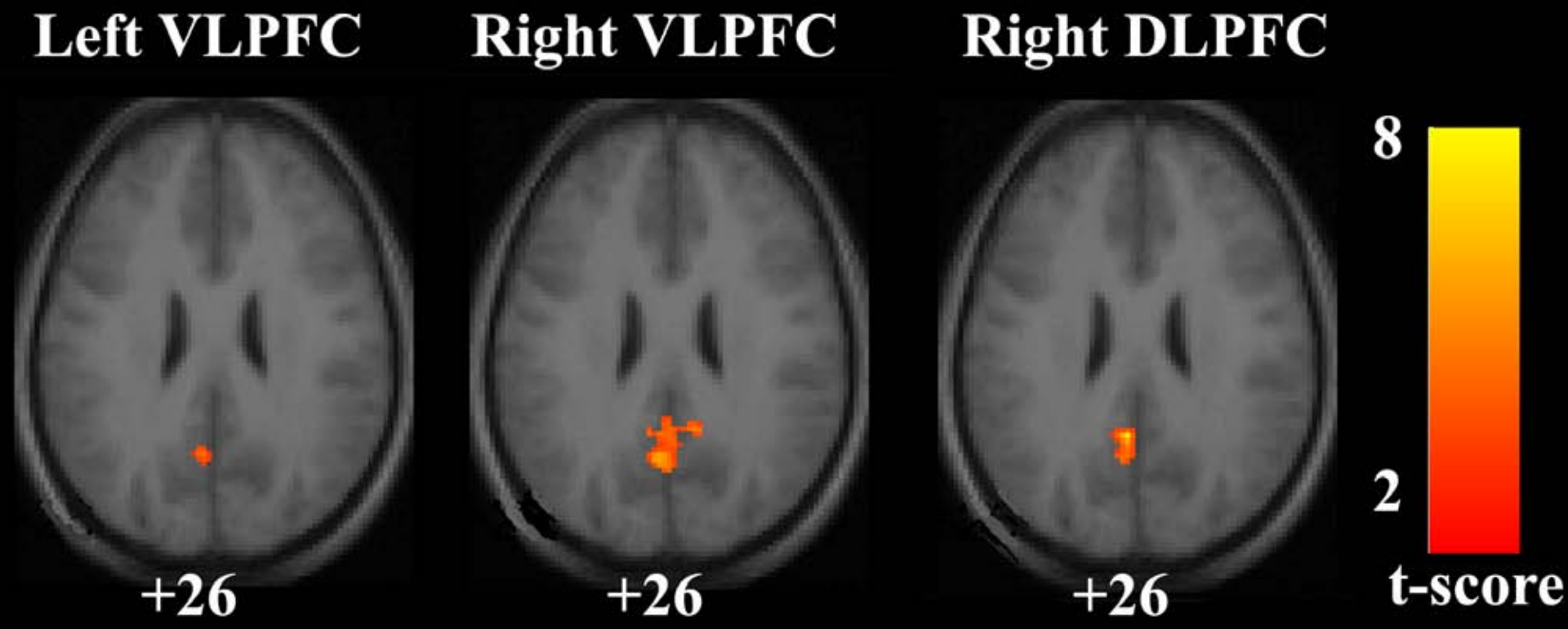
Critchley et al., *Neuroimage* 2005

Network-Based Neurodegeneration
Fire Together, Wire Together, Expire Together



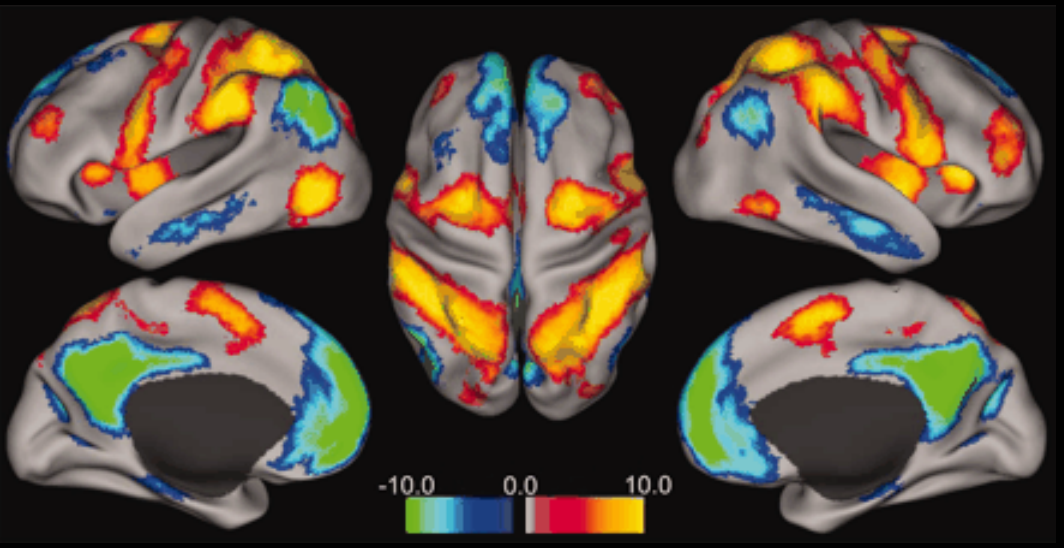
Seeley et al., *Neuron*, 2009

Inter-Network Interactions

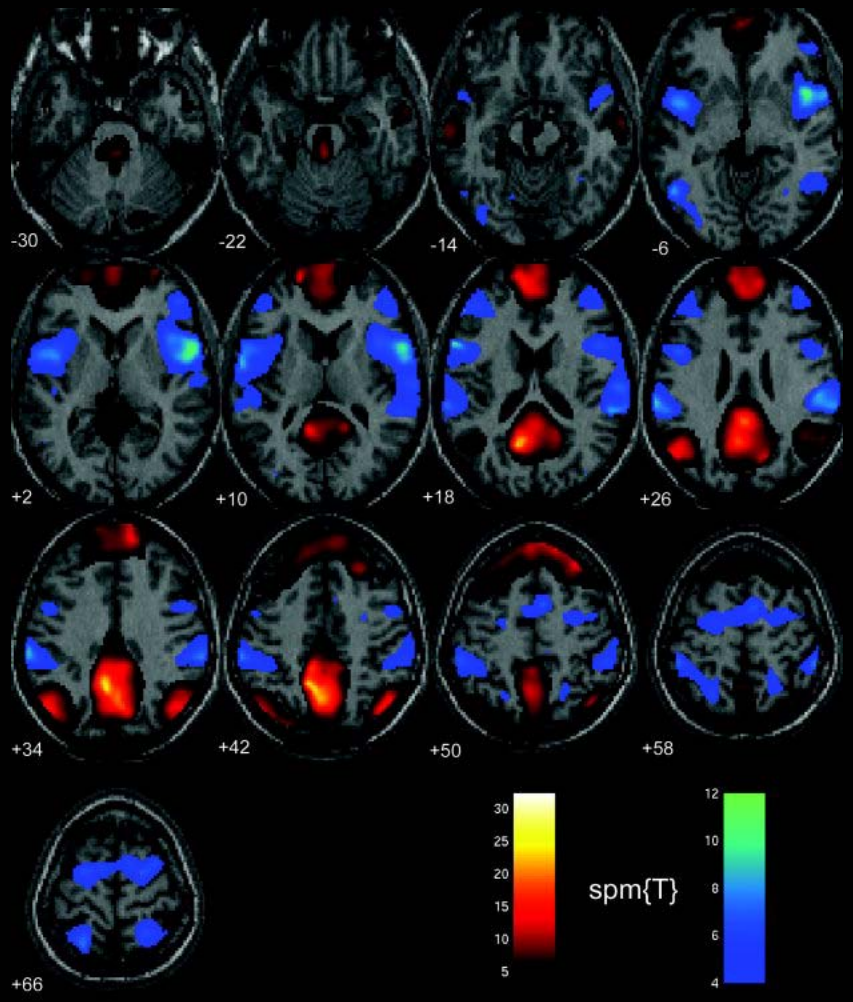


Greicius et al., *PNAS*, 2003

Inter-Network Interactions

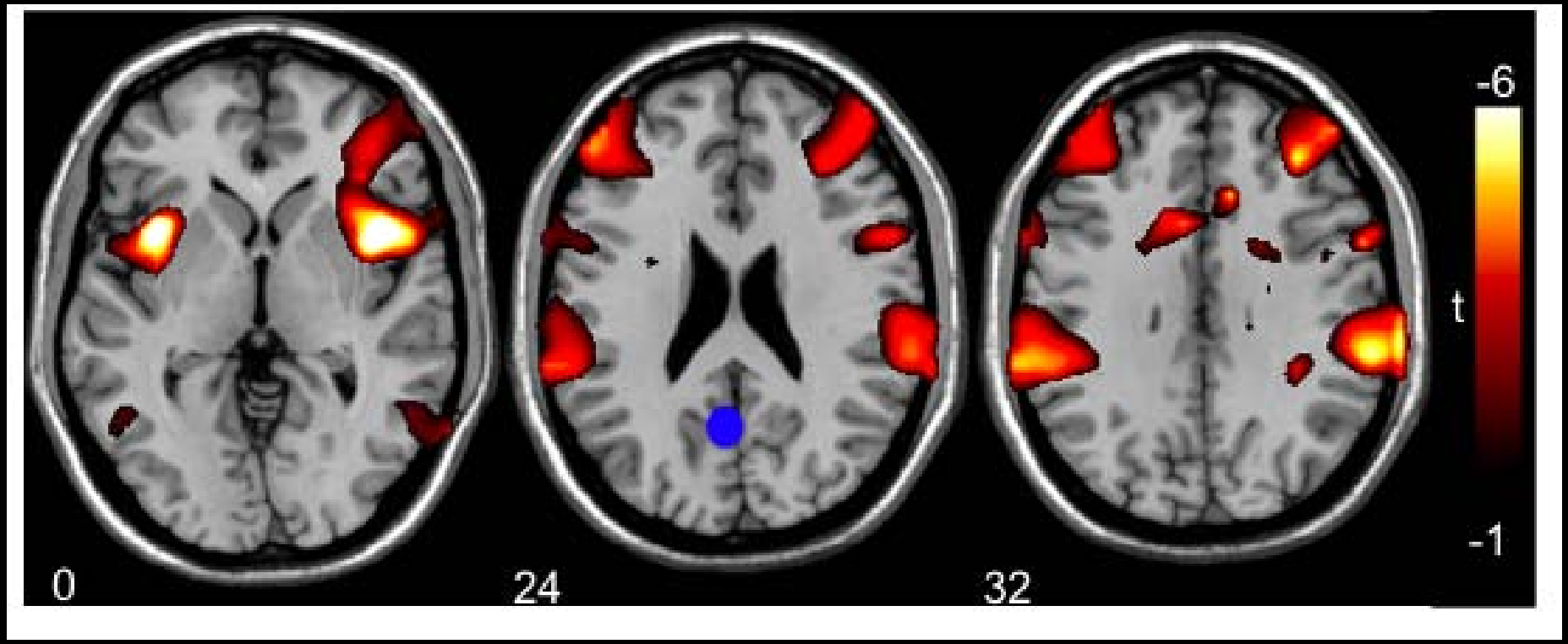


Fox et al., *PNAS*, 2005



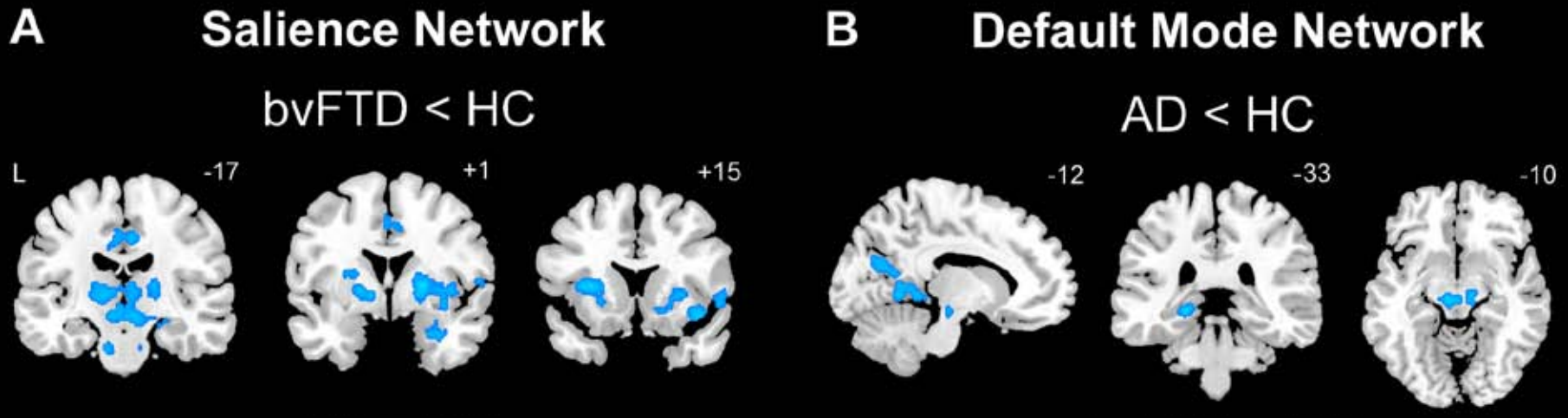
Fransson, *Hum Brain Mappp*, 2005

Anti-Correlations at the Group Level (careful physio correction, no global scaling)



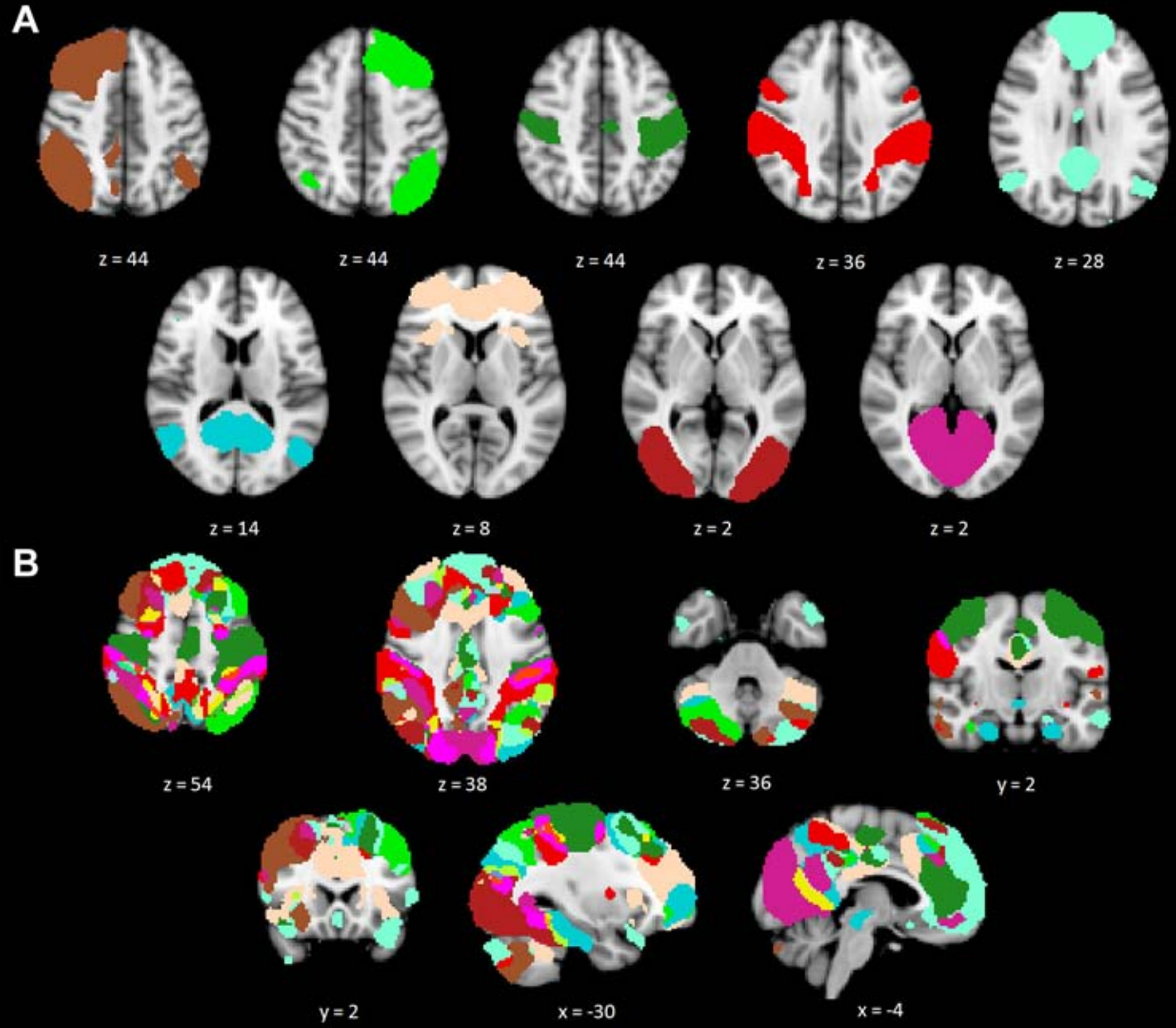
Chang and Glover, *Neuroimage*, 2010

Inter-Network Interactions in Dementia

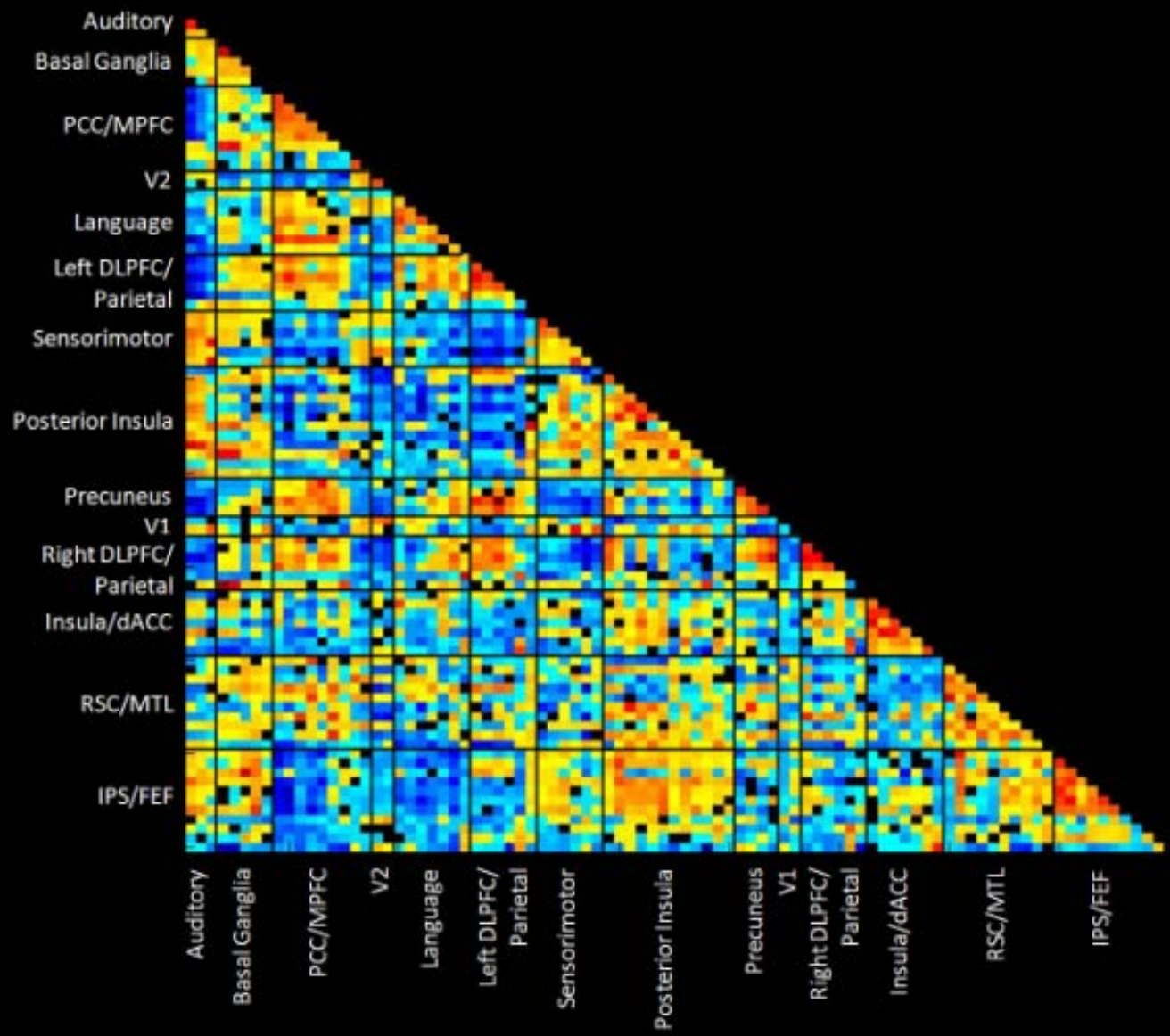


Zhou et al., *Brain* , 2010

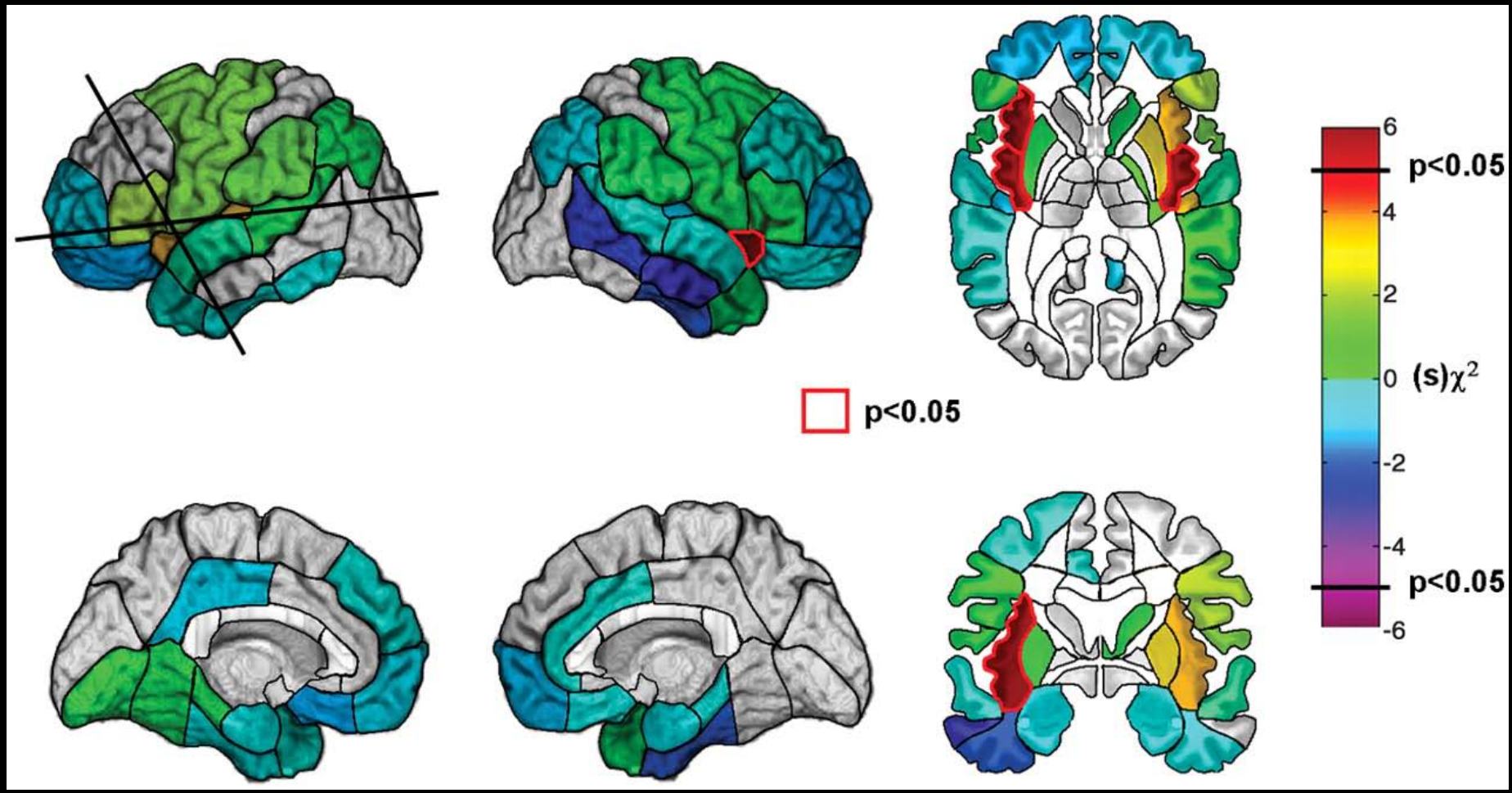
FIND Lab Parcellation (14 ICNs yield 90 ROIs)



Whole-Brain Functional Connectivity Matrix



Insular Lesions and Addiction



Navqi et al., *Science*, 2007

Salience Network and Cue-Induced Urges

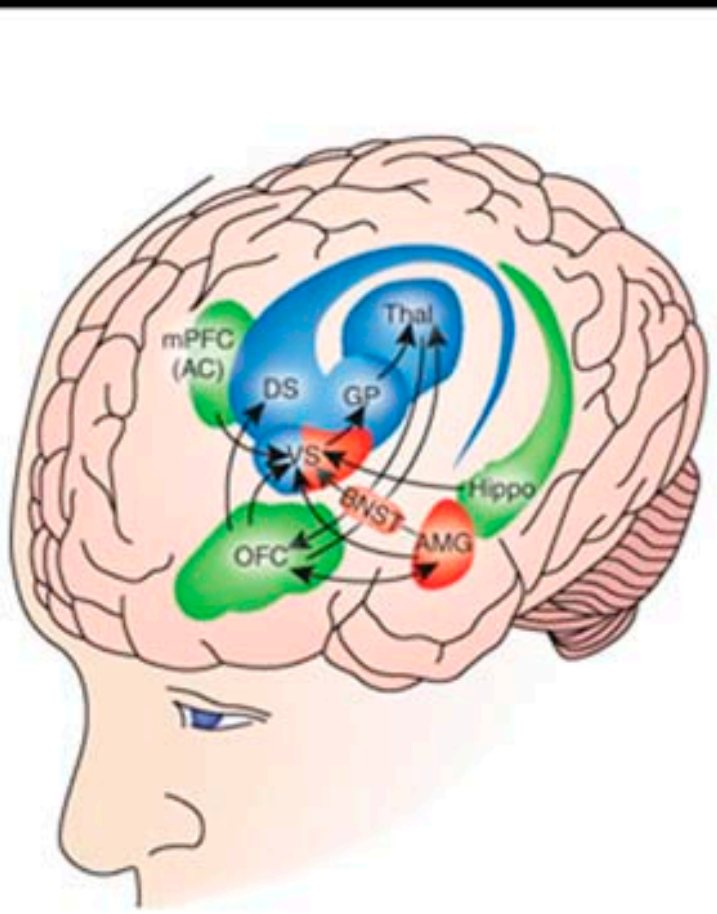
Table 1. Functional imaging studies demonstrating activity in the insula during drug urges[a]

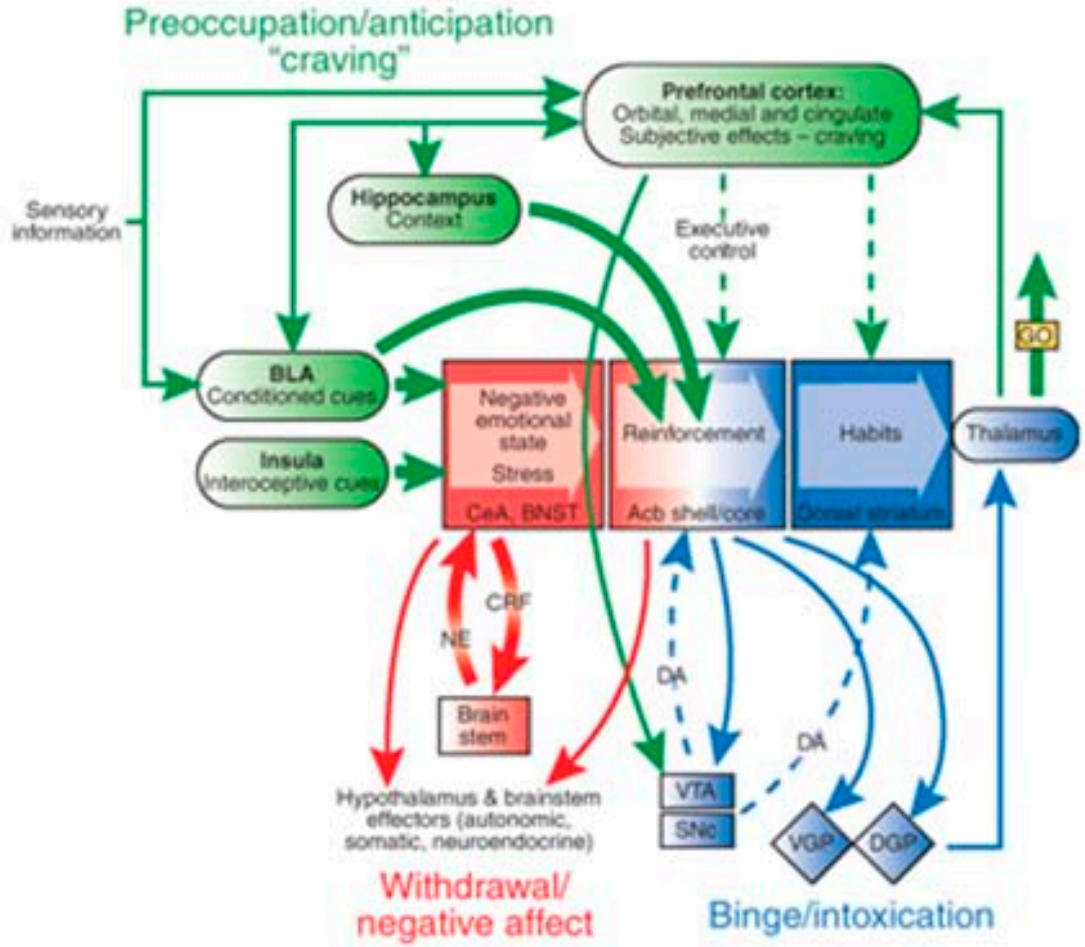
Drug	Insula	OFC[b]	ACC	DLPFC	Amygdala	VS	HF	Refs
Cigarettes	L	L	L,R	L[c]	No activity	No activity	No activity	[129]
Cigarettes	L	R	No activity	L[c]	L,R	L,R	L,R	[130]
Cigarettes	L[c],R[c]	L[c],R[c]	L,R	L[c],R[c]	L	No activity	No activity	[131]
Cigarettes	L[c],R[c]	No activity	L[c],R[c]	L[c]	No activity	No activity	No activity	[115]
Cigarettes	L,R	No activity	L[c],R[c]	L[c],R[c]	No activity	No activity	No activity	[132]
Cigarettes	R	L	L	R	No activity	No activity	No activity	[133]
Cigarettes	R[c]	R[c]	R[c]	R[c]	R[c]	R[c]	L[c],R[c]	[134]
Cocaine	L	No activity	R	No activity	L,R	R	No activity	[135]
Cocaine	L[c]	L[c]	No activity	R[c]	L[c]	No activity	No activity	[136]
Cocaine	L[c],R[c]	L[c],R[c]	L	No activity	L,R	R	No activity	[137]
Cocaine	L,R[c]	L[c],R[c]	No activity	No activity	No activity	No activity	No activity	[138]
Cocaine	R	No activity	L	L,R	No activity	No activity	No activity	[139]
Cocaine	R	No activity	L,R	L	No activity	No activity	No activity	[140]
Alcohol	L,R	L[c],R[c]	L[c],R	No activity	No activity	L[c],R	L	[141]
Alcohol	L,R	No activity	L	L	No activity	No activity	No activity	[142]
Heroin	L	L	L,R	No activity	No activity	No activity	No activity	[143]

[a]All are studies of cue-induced urges, except Ref. [134], which is a study of abstinence-induced urges.
[b]Abbreviations: ACC, anterior cingulate cortex; DLPFC, dorsolateral prefrontal cortex; HF, hippocampal formation; L, left; OFC, orbitofrontal cortex; R, right; VS, ventral striatum.
[c]Indicates correlation with self-reported urges. Note that activity in the insula is frequently correlated with subjective urges. Also note the paucity of activation in subcortical structures, which indicates that conscious urges mediated by the insula might be dissociable from processes mediated by these subcortical regions.

Naqvi and Bechara, *Trends Neurosci*, 2008

Network Interactions in Addiction





Koob and Volkow, *Neuropsychopharmacology*, 2010

Imaging ICNs in Addiction

- Brain can be segregated into a 14+ ICNs
- Several potential networks of interest in addiction
- Consider inter- as well as intra-network changes
- Different drugs may alter networks differentially
- Future studies: genetics, plasticity, pharmacology

Collaborators

Stanford
Vinod Menon
Bob Dougherty
Gary Glover
Jeske Damoiseaux
Will Shirer

UCSF
Bruce Miller
Bill Seeley
Helen Zhou

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Reviews

Craig, *Nat Rev Neurosci*, 2002
Seeley et al., *Alzheimer Dis Assoc Disord*, 2007
Naqvi and Bechara, *Trends Neurosci*, 2008